(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: 0 404 052 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: 08.12.93 Bulletin 93/49

(51) Int. Cl.^{5}: G02B 6/34, G02B 27/28

(21) Application number: 90111547.7

(22) Date of filing: 19.06.90

(54) Polarization coupler.

(30) Priority: 19.06.89 JP 154661/89

(43) Date of publication of application: 27.12.90 Bulletin 90/52

(45) Publication of the grant of the patent: 08.12.93 Bulletin 93/49

(84) Designated Contracting States: DE FR GB

(56) References cited:
DE-A- 3 236 149
OPTICAL FIBER COMMUNICATION CONFERENCE AND 6TH INTERNATIONAL CONFERENCE ON INTEGRATED OPTICS AND OPTICAL FIBER COMMUNICATION TECHNICAL DIGEST, 19-22 January 1987, page 80, Washington, US; W.L. EMKEY et al.: "Single-mode polarization-selective coupler using fiber lenses"
PATENT ABSTRACTS OF JAPAN, vol. 8, no. 165 (P-291), 31 July 1984 ; & JP-A-59061815 (FUJITSU K.K.) 09.04.1984

(56) References cited:
PATENT ABSTRACTS OF JAPAN, vol. 5, no. 150 (P-81), 22 September 1981; & JP-A-56083701 (NIPPON DENSHIN) 08.07.1981
PATENT ABSTRACTS OF JAPAN, vol. 9, no. 320 (P-413), 14 December 1985; & JP-A-60146216 (KOGYO GIJUTSUIN) 01.08.1985

(73) Proprietor: FUJITSU LIMITED
1015, Kamikodanaka Nakahara-ku
Kawasaki-shi Kanagawa 211 (JP)

(72) Inventor: Takamatsu, Hisashi
458-3-1004, Shiboguchi, Takatsu-ku
Kawasaki-shi, Kanagawa 213 (JP)
Inventor: Naganuma, Norihisa
3-35-16-102, Utsukushigaokanishi, Midori-ku
Yokohama-shi, Kanagawa 227 (JP)
Inventor: Abe, Kenichi
1-1-31-203, Fukamihigashi
Yamato-shi, Kanagawa 242 (JP)

(74) Representative: Lehn, Werner, Dipl.-Ing. et al
Hoffmann, Eitle & Partner, Patentanwälte,
Postfach 81 04 20
D-81904 München (DE)

EP 0 404 052 B1

Description

The present invention relates to a polarization coupler for introducing light from two laser diodes into a single optical fibre or the like and also to a process of manufacturing such a polarization coupler.

The document Optical Fibre Communication Conference and 6th International Conference on Integrated Optics and Optical Communication", Technical Digest, Paper TUJ5, page 80 by W.L. Emkey et al, "Single-Mode Polarization-Selective Coupler Using For Fibre Lenses" describes a polarization selective coupler. The device comprises a first polarization maintaining fibre and a second polarization maintaining fibre having a polarization plane perpendicular to the polarization plane of the first polarization maintaining fibre. Said device is particularly designed to combine the light output from the two polarization maintaining fibres into a single output fibre. By employing fibre lenses and a rutile crystal at the end of the first and second polarization maintaining fibres the device achieves a minimization of changes in coupling loss due to relative translational misalignments of the axis of the two polarization maintaining fibres. In the opposite direction the polarization selective coupler operates as a polarization selective splitter splitting light output from the single fibre into the two polarization maintaining fibres with orthogonal polarisation planes. In this polarization selective coupler the rutile crystal interposed between the two polarization maintaining fibres and the output fibre merely combines light from the two polarization maintaining fibres. Thus, the light propagating in the first polarization maintaining fibre is transmitted to the output fibre and the light from the second polarization maintaining fibre is coupled into the output fibre via the rutile crystal. In this respect a polarization coupler is described having first and second polarization maintaining fibres disposed adjacent to eachother, having their geometrical axis parallel to each other and having input light transmitted therethrough with orthogonal polarizations in the two fibres, a third fibre having a geometrical axis disposed on an extension line of the geometrical axis of the first fibre and birefringent plate, i.e. a rutile crystal disposed between the first and second fibres and the third fibre such that the ordinary ray of light originating from the first fibre and the extraordinary ray of light originating from the second fibre are both transmitted to the third fibre.

In order to build up an optical fibre communication system of high reliability requiring the use of a highly reliable polarization coupling device, it is effective to duplicate the light source, such as a laser diode or the like in an optical transmitter. In this instance the two light sources are constructed in advance such that output beams of light therefrom may be introduced into an optical fibre and at an initial stage of the starting operation of the system only one of the two light sources is used. If this light source fails, the other light source is alternatively used to prevent a possible system down. A polarization coupler is used to introduce in a highly reliable system of the type mentioned beams of polarized light from two light sources (linearly polarized or elliptically polarized light approximating linearly polarized light) into a common optical fibre.

Incidently, in an optical transmitter, part of the optical output is sometimes split and power of the thus split light is monitored in order to watch, for example, deterioration of the light source with the passage of time. A polarization coupler suitable for such monitoring is thus demanded.

Conventionally, a polarization coupler which includes a polarizing prism and a beam splitter having a branching ratio free from polarization dependency is known as a polarization coupler which allows such monitoring as described above. In an optical transmitter which includes a polarization coupler of the type just mentioned, beams of light emitted from, for example, two laser diodes and having polarization planes perpendicular to each other are collimated by a lens and introduced into the same light path by way of a polarizing prism so that they are introduced into an optical fiber by means of a beam splitter, having a branching ratio free from polarization dependency, and a condensing lens. Monitoring for the light intensity is effected using light split by the beam splitter.

Since a conventional polarization coupler is constituted using a polarizing prism for the composition of beams of light (linearly polarized light in ordinary cases) from two light sources while using a beam splitter having a branching ratio free from polarization dependency for the monitoring, and besides requiring a lens for forming a parallel light beam system in this manner, this imposes a limitation on the miniaturization of the device.

Further, since very accurate adjustment of the optical axis is required in assembly of the device, the operability in production is not high.

In addition, since the branching ratio between main signal light and light from the monitoring is determined decisively by a branching ratio of the beam splitter it cannot be varied readily.

Therefore it is an object of the present invention to provide a polarization coupler which is suitable for miniaturization and high in operability in production and can be set readily to a desired branching ratio in monitoring.

The above object is solved by a polarization coupler having the features a) to i) of claim 1.

According to the present invention, since formation of a parallel light beam system is not required and hence adjustment of the optical axis of a parallel light beam system is not required either, a polarization coupler is provided which is high in operability in production and is suitable for miniaturization. Further,

since a possible increase in loss arising from formation of a parallel light beam system is eliminated, a polarization coupler is provided, which is low in loss.

With the construction of a polarization coupler having the features a) to l) of claim 1, when the first and second polarization maintaining fibres 2 and 4 are connected to two light sources, main signal light can be extracted from the fifth polarization maintaining fibre 14 while light for monitoring can be extracted from the sixth polarization maintaining fibre 16. The basic construction described in claim 1 can be readily realized by mounting said first to sixth polarization maintaining fibres 2,4,6,12,14,16 and said rotator 8 and said birefringent plate 10 on a substrate.

Where said first to third polarization maintaining fibres 2,4 and 6 are held in a closely contacting relationship with said rotator while said rotator is held in a closely contacting relationship with said birefringent plate 10 and said fourth to sixth polarization maintaining fibres 12,14 and 16 are held in a closely contacting relationship with said birefringent plate 10, the loss of light by the polarization coupler can be restricted to low values.

Where said first and third polarization maintaining fibres 2 and 6 are held in a closely contacting relationship with said second fibre 4 while said fourth and sixth polarization maintaining fibres 12 and 16 are held in a closely contacting relationship with said fifth polarization maintaining fibre 14, the separation angle between an ordinary ray of light and extraordinary ray of light with respect to a unit-thickness of the birefringent plate 10 or alternatively the thickness of the birefringent plate 10 with respect to a unit separation angle between an ordinary ray of light and an extraordinary ray of light can be reduced and consequently the loss of the polarization coupler can be restricted to small values.

Preferably, any one or all of said first to sixth polarization maintaining fibres 2,4,6,12,14 and 16, for example any one of the first, second, fifth and sixth polarization maintaining fibres 2,4,14 and 16 is formed from a birefringent fibre which has different propagation coefficients for light of the HEx-mode and the HEy-mode.

The birefringent fibre may be of the stress inducing type which has a cross-section in which a pair of stress applying portions are provided in the cladding in a symmetrical relationship on opposite sides of the core.

Alternatively said birefringent fibre may be of the stress inducing type which has a cross-section in which an elliptical stress applying portion is provided in the cladding round the core.

Preferably, the predetermined angle (the angle of rotation of light by the rotator 8) is set such that for given orthogonal input light polarization directions the power of the extraordinary ray of light which is transmitted through said fifth polarization maintaining fibre is higher than the power of the ordinary ray of light which is transmitted through said fourth polarization maintaining fibre and the power of the ordinary ray of light which is transmitted through said fifth polarization maintaining fibre is higher than the power of the extraordinary ray of light which is transmitted through said sixth polarization maintaining fibre.

The setting of the predetermined angle may be effected by setting the orientation of the optical axis of a half-wave plate which is employed as the rotator 8.

Alternatively, the setting of the predetermined angle may be realized by the setting of a predetermined magnetic field which is applied to a Faraday rotator employed as the rotator 8.

Further, the above stated object is solved by a process of producing a polarization coupler comprising the steps a) to d) of claim 11.

The above and other features and advantages of the present invention and the manner of realizing them in practise will become more apparent and the invention itself will be best understood, from a study of the following description including the appended claims, with reference to the attached drawings which show some preferred embodiments of the invention.

In the Figures:

Fig. 1A is a plan view of a polarization coupler showing basic construction of the present invention;

Fig. 1B is a front elevational view of the polarization coupler of Fig. 1A:

Fig. 2 is a plan view of a polarization coupler showing a preferred embodiment of the present invention;

Figs. 3A and 3B are schematic views illustrating an effect arising from the structure of the embodiment of the present invention shown in FIG. 2 wherein a polarization maintaining fiber, a rotator and a birefringent plate are held in a closely contacting relationship with each other;

Fig. 4 is a diagrammatic view illustrating a birefringent fiber which can be used as a polarization maintaining fiber;

Fig. 5 is a similar view but illustrating another birefringent fiber which can be used as a polarization maintaining fiber;

Figs. 6A, 6B and 6C are schematic views showing different steps of a process of producing a polarization coupler according to the present invention; and

Fig. 7 is a schematic illustration showing a principal portion of an optical transmitter which is constructed using a polarization coupler of the present invention.

Description of the Preferred Embodiments

Referring first to Fig. 2, there is shown a polari-

zation coupler according to the present invention wherein various components are secured to a substrate 18 made of quartz or the like and having a flat surface thereon. Where first to sixth polarization maintaining fibers 2, 4, 6, 12, 14 and 16 are secured to the substrate 18 in this manner, it is easy to position the geometrical center axes of the individual fibers in the same plane. A function of the polarization coupler will be described subsequently with reference to Fig. 2.

Beams of light which are transmitted by way of the first and second fibers 2 and 4 from two light sources (not shown) have polarization planes perpendicular to each other. It is assumed now that the polarization plane of light transmitted by way of the first fiber 2 extends perpendicularly to the plane of Fig. 2 while the polarization plane of light transmitted by way of the second fiber 4 extends in parallel to the plane of Fig. 2. In this instance, the orientation of the optical axis of the birefringent plate 10 is set such that the polarization plane of an ordinary ray of light therethrough may extend in parallel to the plane of Fig. 2 while the polarization plane of an extraordinary ray of light extends perpendicularly to the plane of Fig. 2.

If beams of light are introduced into the rotator 8 from the first and second fibers 2 and 4, then the polarization planes of them are rotated by a predetermined angle in the same direction, and then the beams of light having the thus rotated polarization planes are introduced into the birefringent plate 10. If a beam of light having a polarization plane which extends neither perpendicularly nor in parallel to the plane of Fig. 2 is introduced into the birefringent plate 10, then it is split into an ordinary ray of light and an extraordinary ray of light, and the thus split rays of light are normally transmitted in different directions such that the ordinary ray of light advances straightforwardly. Accordingly, the ordinary rays of light from the birefringent plate 10 can be introduced into the fourth and fifth fibers 12 and 14 disposed in a coaxial relationship with the first and second fibers 2 and 4, respectively. Meanwhile, if the optical axis of the birefringent plate 10 is set in a specific manner, then an extraordinary ray of light can be transmitted in a direction inclined by a predetermined angle with respect to the geometrical axis of each fiber on a plane including the geometrical axes. Accordingly, if the thickness of the birefringent plate 10 is set in a specific manner, then the extraordinary ray of light from the first fiber 2 can be introduced into the fifth fiber 14 while the extraordinary ray of light from the second fiber 4 can be introduced into the sixth fiber 16. Further, the ordinary ray of light introduced into the fourth fiber 12 is then introduced into the third fiber 6 while maintaining its polarization plane, whereafter it passes through the rotator 8 and then through the birefringent plate 10 and is then introduced into the sixth fiber 16. Accordingly, light introduced into the fifth fiber 14 can be extracted as a main signal output while light introduced into the sixth fiber 16 can be extracted for monitoring.

If it is assumed that the angle of rotation of the polarization plane (the aforementioned predetermined angle) by the rotator 8 is set such that, for example, 5 % of light transmitted by way of the first fiber 2 (first input light) may be introduced as an ordinary ray of light into the fourth fiber 12, ignoring loss, the remaining 95 % of the light is introduced as an extraordinary ray of light into the fifth fiber 14. In this instance, since the polarization plane of the light transmitted by way of the second fiber 4 (second input light) extends perpendicularly to the polarization plane of the first input light, 5 % of the second input light is introduced as an extraordinary ray of light into the sixth fiber 16 while the remaining 95 % is introduced as an ordinary ray of light into the fifth fiber 14. Accordingly, it is possible to combine 95 % of the first and second input light and introduce the same into the fifth fiber 14. It is to be noted that, as for light for the monitoring to be introduced into the sixth fiber 16, while the extraordinary ray of light originating from the second input light is 5 % of the original second input light, the ordinary ray of light originating from the first input light is 4.75 % of the original first input light because second 5 % is removed as an extraordinary ray of light from 5 % of the original fist input light. Since the difference is very small, however, it does not make any essential matter in monitoring powers of the first and second input light.

In the present embodiment, the first, second and third fibers 2, 4 and 6 are held in a closely contacting relationship with the rotator 8 which is in turn held in a closely contacting relationship with the birefringent plate 10 while the fourth, fifth and sixth fibers 12, 14 and 16 are held in a closely contacting relationship with the birefringent plate 10. An effect achieved by such construction will be described below with reference to Figs. 3A and 3B. Where there is a spacing between the first and fourth fibers 2 and 12 as shown in Fig. 3A, light radiated from an end face of a core of the first fiber 2 is expanded significantly due to the difference between the refractive index of the core of the first fiber 2 and the refractive index of air, and consequently, a great loss is caused when the light is introduced into the core of the fourth fiber 12 by way of the end face of the core. On the other hand, where the rotator 8 and the birefringent plate 10 held in a closely contacting relationship with each other are held in a closely contacting relationship with the end faces of fibers as shown in Fig. 3B, such expansion of the beam of light is caused to be reduced because normally the refractive indices of the rotator and the birefringent plate are not different by a great amount from the refractive index of the cores, and consequently, an optical coupling which is low in loss can be obtained. Accordingly, where the construction of

the present embodiment is employed, a polarization coupler which has reduced loss can be provided compared with an alternative arrangement wherein various members are disposed such that an air gap may be provided between the rotator 8 and the first, second and third fibers 2, 4 and 6 and/or between the birefringent plate 10 and the fourth, fifth and sixth fibers 12, 14 and 16.

In the present embodiment, the first and third fibers 2 and 6 are held in a closely contacting relationship with the second fiber 4 while the fourth and sixth fibers 12 and 16 are held in a closely contacting relationship with the fifth fiber 14 as shown in Fig. 2. With this construction, since the geometrical center axes of the individual fibers can be disposed proximately to each other, if the separation angle of the birefringent plate 10 between an ordinary ray of light and an extraordinary ray of light is fixed, then the thickness of the birefringent plate 10 can be reduced, but on the contrary if the thickness of the birefringent plate 10 is fixed, then the separation angle between an ordinary ray of light and an extraordinary ray of light can be reduced. Consequently, the polarization coupler can be reduced in loss.

The first to sixth fibers 2, 4, 6, 12, 14 and 16 may each be formed from a birefringent fiber which has different propagation coefficients for light of a HE_x mode and for light of a HE_y mode. Here, the HE_x mode is that one of HE_{11} modes, which can be transmitted through a single mode fiber, which has an electric field in an x-axis direction perpendicular to the transmitting direction of light while the HE_y mode is that one of the HE_{11} modes which has an electric field in a y-axis direction perpendicular to the transmitting direction of light and also to the x-axis direction. Since the first to fourth fibers 2, 4, 6 and 12 are required to allow transmission therethrough only of a polarized light component having a predetermined polarization plane while the fifth and sixth fibers 14 and 16 are required to allow transmission therethrough of two polarized light components having perpendicular polarization planes, the first to fourth fibers 2, 4, 6 and 12 may otherwise be formed each from a polarization maintaining fiber which is designed such that it may present significantly different transmission losses with light of the HE_x mode and the HE_y mode, or in other words, which is designed such that light of only one mode may be transmitted therein.

An example of construction of a birefringent fiber will be described with reference to Fig. 4 in which construction of an end face of the first fiber 2 is shown by way of an example. The birefringent fiber shown is of the stress inducing type wherein it has, as viewed in section, a pair of stress applying portions 2c and 2d provided in the cladding 2b in a symmetrical relationship on opposite sides of the core 2a. The stress applying portions 2c and 2d are formed from a material having a different coefficient of linear expansion from that of the cladding 2b. With this construction, since the core 2a is provided with different stresses in the x-axis direction in which the core 2a and the stress applying portions 2c and 2d extend and the y-axis direction perpendicular to the x-axis direction, the core 2a has some anisotropy in refractive index, and consequently, the birefringent fiber can maintain the polarization plane of light of a particular mode. In other words, linearly polarized light having a polarization plane parallel to the x-axis or linearly polarized light having another polarization plane parallel to the y-axis can be transmitted in the birefringent fiber without changing the polarization condition.

Referring now to Fig. 5, there is shown another example of construction of a birefringent fiber. In the present example, a stress applying portion 2e having a substantially elliptical section is provided in the cladding 2b around the core 2a such that the major axis of the ellipse of the section thereof may be positioned on the x-axis while the minor axis is positioned on the y-axis. Also with this construction, the core 2a is provided with some birefringence and consequently can maintain the polarization plane of light of a particular mode.

A half-wave plate may be employed for the rotator 8. In this instance, setting of the angle of rotation (predetermined angle) can be achieved by setting of the orientation of the optical axis of the half-wave plate. The rotator 8 may otherwise be constituted from a Faraday rotator to which a predetermined magnetic field is applied. In this instance, setting of the angle of rotation can be achieved by setting of the predetermined magnetic field. According to the present invention, the branching ratio of light for monitoring with respect to the main signal output can be adjusted readily by arbitrarily setting the angle of rotation in this manner.

By the way, the power of light required for the monitoring is generally low. Accordingly, in order to assure a sufficiently high power of a main signal output, the angle of rotation of light by the rotator 8 is preferably set such that for given orthogonal input light polarization directions the power of the extraordinary ray of light which is transmitted in the fifth fiber 14 is higher than the power of the ordinary ray of light which is transmitted in the fourth fiber 12 while the power of the extraordinary ray of light which is transmitted in the fifth fiber 14 is higher than the power of the ordinary ray of light which is transmitted in the sixth fiber 16.

Different steps of a process of producing a polarization coupler will be described subsequently with reference to Figs. 6A, 6B and 6C. First, a first mother fiber 20 which is to later make the first and fourth fibers 2 and 12, a second mother fiber 22 which is to make the second and fifth fibers 4 and 14 and a third mother fiber 24 which is to make the third and sixth fibers 6 and 16 are fixed to a substrate 18, in the form

of a flat plate made of quartz glass or the like, as shown in Fig. 6A using, for example, a bonding agent. They may otherwise be fixed by soldering to a substrate which is plated in advance with gold on the fixing face thereof. In the present example, the second mother fiber 22 is held in a closely contacting relationship with the first and third mother fibers 20 and 24 on the substrate 18. The mother fibers 20, 22 and 24 have maintained polarization planes (polarization planes of linearly polarized light transmitted while being maintained) which extend in parallel or perpendicularly to each other. In the present example, the first mother fiber 20 is disposed such that the x-axis thereof in Fig. 4 extends perpendicularly to the fixing surface of the substrate while the y-axis extends in parallel to the fixing surface, and the second and third mother fibers 22 and 24 are disposed such that the x-axes thereof extend in parallel to the substrate fixing surface while the y-axes extend perpendicularly to the substrate fixing surface.

Subsequently, the mother fibers 20, 22 and 24 secured to the substrate 18 are cut in a predetermined cutting width using a cutting saw or the like such that the opposing cut faces thereof may be positioned in the same plane as shown in FIG. 6B, thereby dividing the first mother fiber 20 into first and fourth fibers 2 and 12, the second mother fiber 22 into second and fifth fibers 4 and 14 and the third mother fiber 24 into third and sixth fibers 6 and 16. In this instance, a groove or slit 26 may be formed on the substrate 18 in a shape in accordance with a driving radius of the cutting saw due to a dispersion or the like in an operation for the production, but there will be no trouble with such groove 26.

After that, a rotator 8 and a birefringent plate 10 which are integrated in advance with each other using an optical bonding agent or the like are inserted between the first, second and third fibers 2, 4 and 6 and the fourth, fifth and sixth fibers 12, 14 and 16 and are secured to the latter by means of an optical bonding agent or the like as seen in Fig. 6C.

Finally, the third fiber 6 and the fourth fiber 12 are adhered to each other, for example, by fusion such that the maintaining polarization planes thereof may extend in parallel or perpendicularly to each other. Confirmation of a maintaining polarization plane of a fiber can be effected by irradiating a beam of visible laser upon the fiber sidewardly to confirm a stress applying portion of the fiber.

Referring now to Fig. 7, there is shown construction of a main portion of an optical transmitter to which a polarization coupler of the present invention is applied. Reference numeral 28 denotes a laser diode connected to the first fiber 2, 30 another laser diode connected to the second fiber 4, and 32 a monitoring photodiode connected to the sixth fiber 16. According to the construction, light from either of the laser diodes 28 and 30 can be outputted by way of the fifth fiber 14. Accordingly, the reliability of the optical transmitter by the duplicating of the light source can be improved. Further, since optical outputs of the laser diodes 28 and 30 can be split at substantially equal branching ratios from a main signal route to detect powers thereof, a deterioration of an operating laser diode with the passage of time can be watched on an on-line basis.

While in the preferred embodiments shown in the drawings the third and fourth fibers 6 and 12 are produced from different mother fibers, the first and third mother fibers may otherwise be made common to omit connection of the third and fourth fibers 6 and 12 by fusion.

Claims

1. A polarization coupler, comprising
   a) a first polarization maintaining fiber (2) for transmitting first input light therethrough while maintaining the polarization plane of the same;
   b) a second polarization maintaining fiber (4) having a geometrical center axis disposed in parallel to the geometrical center axis of said first polarization maintaining fiber (2) for transmitting therethrough second input light having a polarization plane perpendicular to the polarization plane of the first input light while maintaining the polarization plane of said second input light;
   c) a third polarization maintaining fiber (6) having a first portion having a geometrical center axis parallel to the geometrical center axes of said first and second polarization maintaining fibers (2, 4) on a plane including the geometrical center axes of said first and second polarization maintaining fibers (2, 4), and having a second portion not restricted to this direction;
   d) a rotator (8) for rotating the polarization planes of light outputted from said first, second and third polarization maintaining fibers (2, 4, 6) by a predetermined angle and in the same direction;
   e) a birefringent plate (10) for separating light having polarization planes rotated by said rotator (8) individually into ordinary rays of light and extraordinary rays of light;
   f) a fourth polarization maintaining fiber (12) having a first portion having a geometrical center axis disposed on and arranged in the direction of an extension line of the geometrical center axis of said first polarization maintaining fiber (2) and having a second portion not restricted to this direction and arranged for introducing the ordinary ray of light origi-

nating from the first input light into said first portion of said third polarization maintaining fiber (6) via said second portion of said third polarization maintaining fiber (6) while maintaining the polarization plane of said ordinary ray of light;

g) a fifth polarization maintaining fiber (14) having a geometrical center axis disposed on an extension line of the geometrical center axis of said second polarization maintaining fiber (4) for transmitting therethrough the ordinary ray of light originating from said second input light while maintaining the polarization plane of the same; and

h) a sixth polarization maintaining fiber (16) having a geometrical center axis disposed on an extension line of the geometrical center axis of said third polarization maintaining fiber (6) for transmitting therethrough the ordinary ray of light originating from light outputted from said third polarization maintaining fiber (6) while maintaining the polarization plane of the same;

i) said birefringent plate (10) being arranged such that the extraordinary ray of light separated from the first polarization maintaining fiber (2) is transmitted into said fifth polarization maintaining fiber (14), and

the extraordinary ray of light separated from the second polarization maintaining fiber (4) is transmitted into said sixth polarization maintaining fiber (16), and

said fifth and sixth polarization maintaining fibers (14, 16) being arranged such that said extraordinary rays of light are then transmitted through said fifth and sixth polarization maintaining fibers (14, 16) with their planes of polarization being maintained therein.

2. A polarization coupler according to claim 1, wherein said first, second, third, fourth, fifth and sixth polarization maintaining fibers (2, 4, 6, 12, 14, 16), said rotator (8) and said birefringent plate (10) are all mounted on a substrate (18).

3. A polarization coupler according to claim 2, wherein said first, second and third polarization maintaining fiber (2, 4, 6) are held in a closely contacting relationship with said rotator (8) while said rotator (8) is held in a closely contacting relationship with said birefringent plate (10), and said birefringent plate (10) is held in a closely contacting relationship with said fourth, fifth and sixth polarization maintaining fibers (12, 14, 16).

4. A polarization coupler according to claim 3, wherein said first and said third polarization maintaining fibers (2, 6) are held in a closely contacting relationship with said second polarization maintaining fiber (4) while said fourth and sixth polarization maintaining fibers (12, 16) are held in a closely contacting relationship with said fifth polarisation maintaining fiber (14).

5. A polarization coupler according to claim 4, wherein some or all of said first to sixth polarization fibers maintaining fibers (2, 4, 6, 12, 14, 16) are each formed from a birefringent fiber which has different propagation coefficients for light of the HEx mode and the HEy mode.

6. A polarization coupler according to claim 5, wherein said birefringent fiber is of the stress inducing type which has a cross-section in which a pair of stress applying portions (2c, 2d) are provided in the cladding (2b) in a symmetrical relationship on opposite sides of the core (2a).

7. A polarization coupler according to claim 5, wherein said birefringent fiber is of the stress inducing type which has a cross-section in which an elliptical stress applying portion (2e) is provided in the cladding (2b) around the core (2a).

8. A polarization coupler according to claim 1, wherein the predetermined angle is set such that for given orthogonal input light polarization directions the power of the extraordinary ray of light which is transmitted through said fifth polarization maintaining fiber (14) is higher than the power of the ordinary ray of light which is transmitted though said fourth polarization maintaining fiber (12), and the power of the ordinary ray of light which is transmitted through said fifth polarization maintaining fiber (14) is higher than the power of the extraordinary ray of light which is transmitted through said sixth polarization maintaining fiber (16).

9. A polarization coupler according to claim 8, wherein said rotator (8) is formed from a half-wave plate, and the setting of the predetermined angle is effected by the setting of the orientation of the optical axis of said half-wave plate.

10. A polarization coupler according to claim 8, wherein said rotator (8) is formed from a Faraday rotator to which a predetermined magnetic field is applied, and the setting of the predetermined angle is effected by the setting of the predetermined magnetic field.

11. A process of producing a polarization coupler, comprising the following steps:

a) a first step of mounting a first mother fiber (20) which is to later make first and fourth po-

larization maintaining fibers (2, 12), a second mother fiber (22) which is to make second and fifth polarization maintaining fibers (4, 14) and a third mother fiber (24) which is to make third and sixth polarization maintaining fibers (6, 16) onto a substrate (18) such that the maintained polarization planes of said first to third mother fibers (20, 22, 24) extend parallel or perpendicularly to each other, and such that said first to third mother fibers (20, 22, 24) extend parallel to each other;

b) a second step of cutting said first to third mother fibers (20, 22, 24) mounted on said substrate (18) with a predetermined cutting width such that the cut faces thereof are positioned in the same plane, thereby dividing said first mother fiber (20) into the first and fourth polarization maintaining fibers (2, 12) said second mother fiber (22) into the second and fifth polarization maintaining fibers (4, 14) and said third mother fiber (24) into the third and sixth polarization maintaining fibers (6, 16);

c) a third step of inserting a rotator (8) and a birefringent plate (10) between said first, second and third polarization maintaining fibers (2, 4, 6) and said fourth, fifth and sixth polarization maintaining fibers (12, 14, 16) such that the rotator (8) is positioned adjacent to said first, second and third polarization maintaining fibers (2, 4, 6); and

d) a fourth step of connecting said third polarization maintaining fiber (6) and said fourth polarization maintaining fiber (12) to each other such that the maintained polarization planes thereof extend parallel or perpendicularly to each other.

Patentansprüche

1. Polarisationskoppler mit

a) einer ersten Polarisations-aufrechterhaltenen Faser (2) zum Übertragen eines ersten Eingabelichts dadurch unter Aufrechterhalten der Polarisationsebene desselben;

b) einer zweiten Polarisations-aufrechterhaltenen Faser (4) mit einer geometrischen Mittenachse angeordnet parallel zur geometrischen Mittenachse der ersten Polarisations-aufrechterhaltenen Faser (2) zum Übertragen dadurch eines zweiten Eingabelichts mit einer Polarisationsebene senkrecht zur Polarisationsebene des ersten Eingabelichts unter Aufrechterhalten der Polarisationsebene des zweiten Eingabelichts;

c) einer dritten Polarisations-aufrechterhaltenen Faser (6) mit einem ersten Abschnitt mit einer geometrischen Mittenachse parallel zu den geometrischen Mittenachsen der ersten und zweiten Polarisations-aufrechterhaltenen Faser (2, 4) auf einer Ebene einschließlich der geometrischen Mittenachsen der ersten und zweiten Polarisations-aufrechterhaltenen Fasern (2, 4) und mit einem zweiten Abschnitt, der in dieser Richtung nicht beschränkt ist;

d) einem Rotor (8) zum Rotieren der Polarisationsebenen des Lichts, das ausgegeben wird von den ersten, zweiten und dritten Polarisations-aufrechterhaltenen Fasern (2, 4, 6) um einen vorbestimmten Winkel und in derselben Richtung;

e) einer doppelt-brechenden Platte (10) zum Trennen von Licht mit Polarisationsebenen gedreht durch den Rotor (8) auf individuelle Weise in ordentliche Lichtstrahlen und außerordentliche Lichtstrahlen;

f) einer vierten Polarisations-aufrechterhaltenen Faser (12) mit einem ersten Abschnitt mit einer geometrischen Mittenachse angeordnet auf und ausgerichtet in der Richtung einer Verlängerungslinie der geometrischen Mittenachse der ersten Polarisations-aufrechterhaltenen Faser (2) und mit einem zweiten Abschnitt nicht beschränkt auf diese Richtung und angeordnet zum Einführen des ordentlichen Lichtstrahls herrührend von dem ersten Eingabelicht in den ersten Abschnitt der dritten Polarisations-aufrechterhaltenen Faser (6) über den zweiten Abschnitt der dritten Polarisations-aufrechterhaltenen Faser (6) unter Beibehaltung der Polarisationsebene des ordentlichen Lichtstrahls;

g) einer fünften Polarisations-aufrechterhaltenen Faser (14) mit einer geometrischen Mittenachse angeordnet auf einer Verlängerungslinie der geometrischen Mittenachse der zweiten Polarisations-aufrechterhaltenen Faser (4) zum Übertragen dadurch des ordentlichen Lichstrahls herrührend von dem zweiten Eingabelicht unter Aufrechterhaltung der Polarisationsebene desselben; und

h) einer sechsten Polarisations-aufrechterhaltenen Faser (16) mit einer geometrischen Mittenachse angeordnet auf einer Verlängerungslinie der geometrischen Mittenachse der dritten Polarisations-aufrechterhaltenen Faser (6) zum Übertragen dadurch des ordentlichen Lichtstrahls herrührend von Licht ausgegeben von der dritten Polarisations-aufrechterhaltenen Faser (6) unter Beibehaltung der Polarisationsebene derselben, wobei

i) die doppelt-brechende Platte (10) so angeordnet ist, daß der außerordentliche Lichstrahl abgetrennt von der ersten

Polarisations-aufrechterhaltenen Faser (2) übertragen wird in die fünfte Polarisations-aufrechterhaltene Faser (14) und

der außerordentliche Lichtstrahl abgetrennt von der zweiten Polarisations-aufrechterhaltenen Faser (4) übertragen wird in die sechste Polarisations-aufrechterhaltene Faser (16), und

die fünfte und sechste Polarisations-aufrechterhaltene Faser (14, 16) so angeordnet sind, daß die außerordentlichen Lichtstrahlen dann übertragen werden durch die fünfte und sechste Polarisations-aufrechterhaltene Faser (14, 16), wobei ihre Polarisationsebenen dabei aufrechterhalten werden.

2. Polarisationskoppler nach Anspruch 1, dadurch **gekennzeichnet**, daß die erste, zweite, dritte, vierte, fünfte und sechste Polarisations-aufrechterhaltene Faser (2, 4, 6, 12, 14, 16), der Rotor (8) und die doppelt-brechende Platte (10) alle auf einem Substrat (18) angebracht sind.

3. Polarisationskoppler nach Anspruch 2, dadurch **gekennzeichnet**, daß die erste, zweite und dritte Polarisations-aufrechterhaltene Faser (2, 4, 6) in einem engen Kontakt mit dem Rotor (8) gehalten sind, während der Rotor (8) in einem engen Kontakt mit der doppelt-brechenden Platte (10) gehalten ist und die doppelt-brechende Platte (10) in einem engen Kontakt mit der vierten, fünften und sechsten Polarisations-aufrechterhaltenen Faser (12; 14, 16) gehalten ist.

4. Polarisationskoppler nach Anspruch 3, dadurch **gekennzeichnet**, daß die erste und dritte Polarisations-aufrechterhaltene Faser (2, 6) in einem engen Kontakt mit der zweiten Polarisations-aufrechterhaltenen Faser (4) gehalten sind, während die vierte und sechste Polarisations-aufrechterhaltene Faser (12, 16) in einem engen Kontakt mit der fünften Polarisations-aufrechterhaltenen Faser (14) gehalten sind.

5. Polarisationskoppler nach Anspruch 4, dadurch **gekennzeichnet**, daß einige oder alle der ersten bis sechsten Polarisations-aufrechterhaltene Fasern (2, 4, 6, 12, 14, 16) jeweils gebildet sind aus einer doppelt-brechenden Faser, welche verschiedene Ausbreitungskoeffizienten für Licht des HEx-Modus und des HEy-Modus aufweist.

6. Polarisationskoppler nach Anspruch 5, dadurch **gekennzeichnet**, daß die doppelt-brechende Faser vom Spannungs-induzierenden Typ ist, welche einen Querschnitt hat, in dem ein Paar von Spannungs-anlegenden Abschnitten (2c, 2d) vorgesehen ist in dem Überzug (2b) in einer symmetrischen Beziehung auf gegenüberliegenden Seiten des Kerns (2a).

7. Polarisationskoppler nach Anspruch 5, dadurch **gekennzeichnet**, daß die doppelt-brechende Faser vom Spannungs-induzierenden Typ ist, welche einen Querschnitt hat, in dem ein elliptischer Spannungs-anlegender Abschnitt (2e) vorgesehen ist in dem Überzug (2b) um den Kern (2a).

8. Polarisationskoppler nach Anspruch 1, dadurch **gekennzeichnet**, daß der vorbestimmte Winkel so eingestellt ist, daß für vorgegebene orthogonale Eingabelicht-Polarisationsrichtungen die Leistung des außerordentlichen Lichtstrahls, der übertragen wird durch die fünfte Polarisations-aufrechterhaltene Faser (14) höher ist als die Leistung des ordentlichen Lichtstrahls, der übertragen wird durch die vierte Polarisations-aufrechterhaltene Faser (12) und die Leistung des ordentlichen Lichtstrahls, welcher übertragen wird durch die fünfte Polarisations-aufrechterhaltene Faser (14) höher ist als die Leistung des außerordentlichen Lichtstrahls, der übertragen wird durch die sechste Polarisations-aufrechterhaltene Faser (16).

9. Polarisationskoppler nach Anspruch 8, dadurch **gekennzeichnet**, daß der Rotor (8) aus einer Halbwellenplatte gebildet ist und die Einstellung des vorbestimmten Winkels bewirkt wird durch Setzen der Orientierung der optischen Achse der Halbwellenplatte.

10. Polarisationskoppler nach Anspruch 8, dadurch **gekennzeichnet**, daß der Rotor (8) gebildet ist aus einem Faraday-Rotor, an den ein vorbestimmtes magnetisches Feld angelegt ist und das Einstellen des vorbestimmten Winkels bewirkt wird durch Setzen des vorbestimmten magnetischen Feldes.

11. Verfahren zum Herstellen eines Polarisationskopplers mit den folgenden Schritten:

a) einem ersten Schritt des Befestigens einer ersten Mutterfaser (20), welche später die erste und vierte Polarisations-aufrechterhaltene Faser (2, 12) ausmacht, einer zweiten Mutterfaser (22), welche die zweite und fünfte Polarisations-aufrechterhaltene Faser (4, 14) ausmacht und einer dritten Mutterfaser (24), welche die dritte und sechste Polarisations-aufrechterhaltene Faser (6, 16) ausmacht, auf einem Substrat (18), so daß die aufrechterhaltenen Polarisationsebenen der

ersten bis dritten Mutterfaser (20, 22, 24) sich parallel oder senkrecht zueinander erstrecken und so daß die erste bis dritte Mutterfaser (20, 22, 24) sich parallel zueinander erstrecken;

b) einem zweiten Schritt des Schneidens der ersten bis dritten Mutterfaser (20, 22, 24) angebracht auf dem Substrat (18) mit einer vorbestimmten Schnittbreite, so daß die Schnittflächen davon in derselben Ebene positioniert sind, um dadurch die erste Mutterfaser (20) in die erste und vierte Polarisations-aufrechterhaltene Faser (2, 12), die zweite Mutterfaser (22) in die zweite und fünfte Polarisations-aufrechterhaltene Faser (4, 14) und die dritte Mutterfaser (24) in die dritte und sechste Polarisations-aufrechterhaltene Faser (6, 16) zu teilen;

c) einem dritten Schritt des Einsetzens eines Rotors (8) und einer doppelt-brechenden Platte (10) zwischen die erste, zweite und dritte Polarisations-aufrechterhaltene Faser (2, 4, 6) und die vierte, fünfte und sechste Polarisations-aufrechterhaltene Faser (12, 14, 16), so daß der Rotor (8) neben der ersten, zweiten und dritten Polarisatons-aufrechterhaltenen Faser (2, 4, 6) positioniert ist, und

d) einem vierten Schritt des Verbindens der dritten Polarisations-aufrechterhaltenen Faser (6) und der vierten Polarisations-aufrechterhaltenen Faser (12) miteinander, so daß die aufrechterhaltenen Polarisationsebenen davon sich parallel oder senkrecht zueinander erstrecken.

Revendications

1. Un coupleur sensible à la polarisation, comprenant

a) une première fibre conservant la polarisation (2) qui est destinée à transmettre à travers elle une première lumière d'entrée, tout en conservant le plan de polarisation de celle-ci;

b) une seconde fibre conservant la polarisation (4) ayant un axe central géométrique disposé parallèlement à l'axe central géométrique de la première fibre conservant la polarisation (2), et qui est destinée à transmettre à travers elle une seconde lumière d'entrée ayant un plan de polarisation perpendiculaire au plan de polarisation de la première lumière d'entrée, tout en conservant le plan de polarisation de la seconde lumière d'entrée;

c) une troisième fibre conservant la polarisation (6) ayant une première partie qui a un axe central géométrique parallèle aux axes centraux géométriques des première et seconde fibres conservant la polarisation (2, 4), dans un plan qui contient les axes centraux géométriques des première et seconde fibres conservant la polarisation (2, 4), et ayant une seconde partie qui n'est pas restreinte à cette direction;

d) un rotateur (8) destiné à faire tourner d'un angle prédéterminé, et dans la même direction, les plans de polarisation de la lumière qui est émise par les première, seconde et troisième fibres conservant la polarisation (2, 4, 6);

e) une lame biréfringente (10) pour séparer individuellement en rayons de lumière ordinaires et en rayons de lumière extraordinaires la lumière dont les plans de polarisation ont subi une rotation sous l'action du rotateur (8);

f) une quatrième fibre conservant la polarisation (12) ayant une première partie qui a un axe central géométrique disposé sur une ligne de prolongement de l'axe central géométrique de la première fibre conservant la polarisation (2), et orientée dans la direction de cette ligne de prolongement, et ayant une seconde partie qui n'est pas restreinte à cette direction et qui est conçue pour introduire le rayon de lumière ordinaire provenant de la première lumière d'entrée dans la première partie de la troisième fibre conservant la polarisation (6), par l'intermédiaire de la seconde partie de la troisième fibre conservant la polarisation (6), tout en maintenant le plan de polarisation du rayon de lumière ordinaire;

g) une cinquième fibre maintenant la polarisation (14), ayant un axe central géométrique disposé sur une ligne de prolongement de l'axe central géométrique de la seconde fibre conservant la polarisation (4), pour transmettre à travers elle le rayon de lumière ordinaire qui provient de la seconde lumière d'entrée, tout en maintenant le plan de polarisation de ce rayon; et

h) une sixième fibre conservant la polarisation (16), ayant un axe central géométrique disposé sur une ligne de prolongement de l'axe central géométrique de la troisième fibre conservant la polarisation (6) pour transmettre à travers elle le rayon de lumière ordinaire qui provient de la lumière émise par la troisième fibre conservant la polarisation (6), tout en conservant le plan de polarisation de ce rayon;

i) la lame biréfringente (10) étant conçue de façon que le rayon de lumière extraordinaire qui est séparé à partir de la première fibre conservant la polarisation (2) soit introduit dans la cinquième fibre conservant la polarisation (14), et

le rayon de lumière extraordinaire qui est sé-

paré à partir de la seconde fibre conservant la polarisation (4) soit introduit dans la sixième fibre conservant la polarisation (16), et
les cinquième et sixième fibres conservant la polarisation (14, 16) étant disposées de façon que les rayons de lumière extraordinaires soient ensuite transmis à travers les cinquième et sixième fibres conservant la polarisation (14, 16), avec leurs plans de polarisation conservés dans ces fibres.

2. Un coupleur sensible à la polarisation selon la revendication 1, dans lequel les première, seconde, troisième, quatrième, cinquième et sixième fibres conservant la polarisation (2, 4, 6, 12, 14, 16), le rotateur (8) et la lame biréfringente (10) sont tous montés sur un substrat (18).

3. Un coupleur sensible à la polarisation selon la revendication 2, dans lequel les première, seconde et troisième fibres conservant la polarisation (2, 4, 6) sont maintenues dans une relation de contact serré avec le rotateur (8), tandis que le rotateur (8) est maintenu dans une relation de contact serré avec la lame biréfringente (10), et la lame biréfringente (10) est maintenue dans une relation de contact serré avec les quatrième, cinquième et sixième fibres conservant la polarisation (12, 14, 16).

4. Un coupleur sensible à la polarisation selon la revendication 3, dans lequel les première et troisième fibres conservant la polarisation (2, 6) sont maintenues dans une relation de contact serré avec la seconde fibre conservant la polarisation (4), tandis que les quatrième et sixième fibres conservant la polarisation (12, 16) sont maintenues dans une relation de contact serré avec la cinquième fibre conservant la polarisation (14).

5. Un coupleur sensible à la polarisation selon la revendication 4, dans lequel certaines ou la totalité des première à sixième fibres conservant la polarisation (2, 4, 6, 12, 14, 16) sont constituées individuellement par une fibre biréfringente qui a des coefficients de propagation différents pour la lumière du mode HEx et du mode HEy.

6. Un coupleur sensible à la polarisation selon la revendication 5, dans lequel la fibre biréfringente est du type à induction de contraintes, ayant une section transversale dans laquelle une paire de parties d'application de contraintes (2c, 2d) sont disposées dans la gaine (2b), selon une relation symétrique, de part et d'autre du coeur (2a).

7. Un coupleur sensible à la polarisation selon la revendication 5, dans lequel la fibre biréfringente est du type à induction de contraintes, ayant une section transversale dans laquelle une partie d'application de contraintes (2e) de forme elliptique est disposée dans la gaine (2b) autour du coeur (2a).

8. Un coupleur sensible à la polarisation selon la revendication 1, dans lequel l'angle prédéterminé est fixé de façon que pour des directions de polarisation de lumière d'entrée orthogonales données, la puissance du rayon de lumière extraordinaire qui est transmis à travers la cinquième fibre conservant la polarisation (14) soit supérieure à la puissance du rayon de lumière ordinaire qui est transmis à travers la quatrième fibre conservant la polarisation (12), et de façon que la puissance du rayon de lumière ordinaire qui est transmis à travers la cinquième fibre conservant la polarisation (14) soit supérieure à la puissance du rayon de lumière extraordinaire qui est transmis à travers la sixième fibre conservant la polarisation (16).

9. Un coupleur sensible à la polarisation selon la revendication 8, dans lequel le rotateur (8) est formé à partir d'une lame demi-onde, et le réglage de l'angle prédéterminé est effectué par le réglage de l'orientation de l'axe optique de cette lame demi-onde.

10. Un coupleur sensible à la polarisation selon la revendication 8, dans lequel le rotateur (8) est formé à partir d'un rotateur de Faraday auquel un champ magnétique prédéterminé est appliqué, et le réglage de l'angle prédéterminé est effectué par le réglage du champ magnétique prédéterminé.

11. Un procédé de fabrication d'un coupleur sensible à la polarisation comprenant les étapes suivantes :

a) une première étape consistant à monter sur un substrat (18) une première fibre mère (20) qui est destinée à former ultérieurement des première et quatrième fibres conservant la polarisation (2, 12), une seconde fibre mère (22) qui est destinée à former des seconde et cinquième fibres conservant la polarisation (4, 14), et une troisième fibre mère (24) qui est destinée à former des troisième et sixième fibres conservant la polarisation (6, 16), de façon que les plans de polarisation conservés des première à troisième fibres mères (20, 22, 24) s'étendent parallèlement ou perpendiculairement les uns aux autres, et de façon que les première à troisième fibres mères (20, 22, 24) s'étendent parallèlement les unes aux autres;

b) une seconde étape consistant à couper les première à troisième fibres mères (20, 22, 24) montées sur le substrat (18), avec une largeur de coupe prédéterminée, de façon que les faces coupées de ces fibres soient positionnées dans le même plan, pour diviser ainsi la première fibre mère (20) pour donner les première et quatrième fibres conservant la polarisation (2, 12), la seconde fibre mère (22) pour donner les seconde et cinquième fibres conservant la polarisation (4, 14), et la troisième fibre mère (24) pour donner les troisième et sixième fibres conservant la polarisation (6, 16);

c) une troisième étape consistant à intercaler un rotateur (8) et une lame biréfringente (10) entre les première, seconde et troisième fibres conservant la polarisation (2, 4, 6), et les quatrième, cinquième et sixième fibres conservant la polarisation (12, 14, 16), de façon que le rotateur (8) soit placé en position adjacente aux première, seconde et troisième fibres conservant la polarisation (2, 4, 6); et

d) une quatrième étape consistant à connecter l'une à l'autre la troisième fibre conservant la polarisation (6) et la quatrième fibre conservant la polarisation (12), de façon que les plans de polarisation conservés de ces fibres s'étendent parallèlement ou perpendiculairement l'un à l'autre.

FIG. 1A

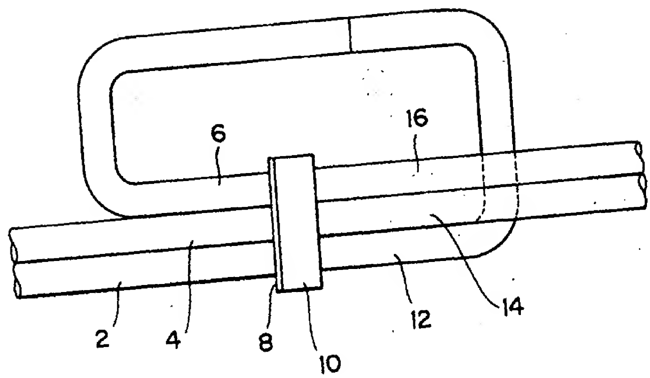

FIG. 1B

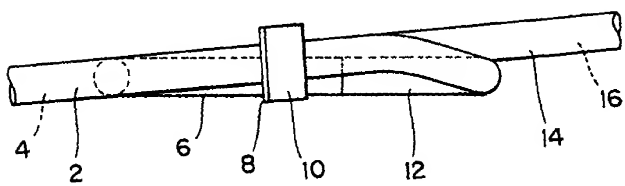

FIG. 2

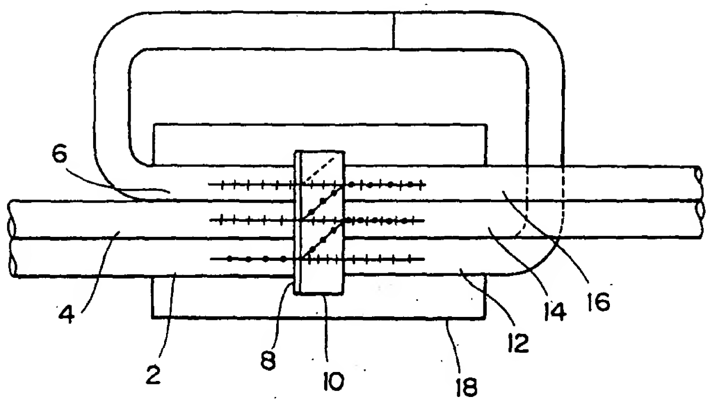

FIG. 3A

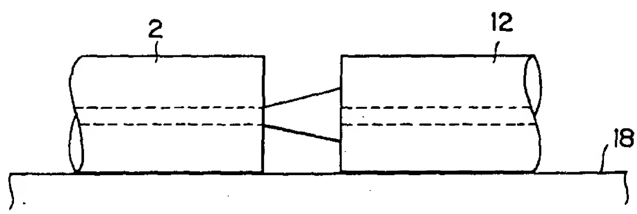

FIG. 3B

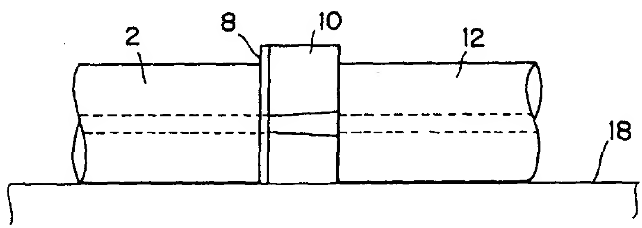

FIG. 4

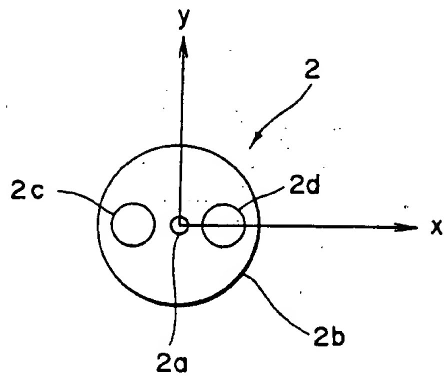

FIG. 5

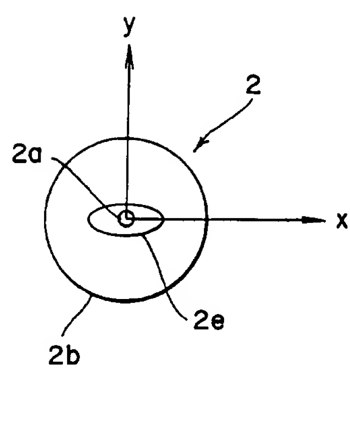

FIG. 6A

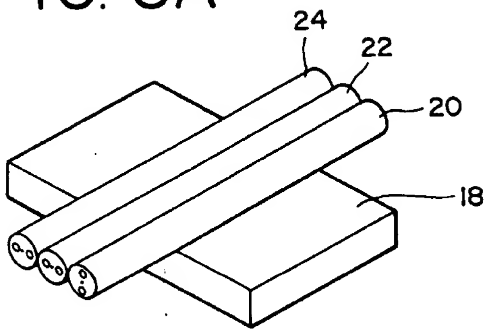

FIG. 6B

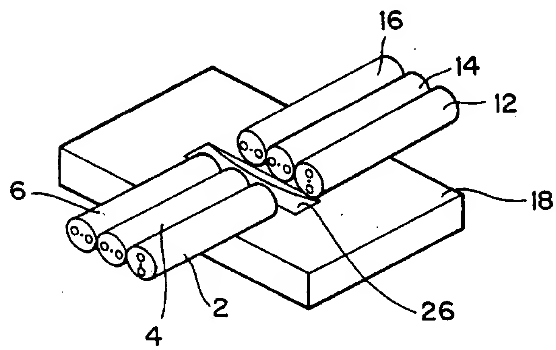

FIG. 6C

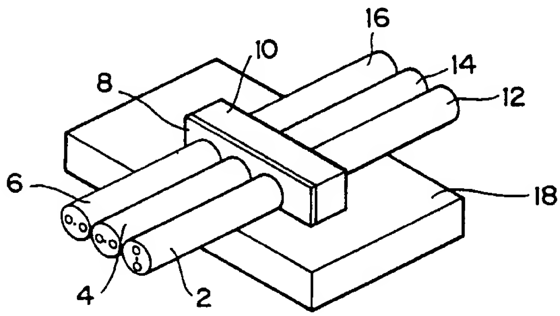

FIG. 7